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(71) Applicant(s)
Robert Bosch GmbH
(Incorporated in the Federal Republic of Germany)
Wernerstrasse 1, Stuttgart-Feuerbach,
D-70442 Stuttgart, Federal Republic of Germany

(72) Inventor(s)
Wolfgang Grothe
Gunther Haas
Martin Freitag

(74) Agent and/or Address for Service
A.A.Thornton & Co
235 High Holborn, LONDON, WC1V 7LE,
United Kingdom

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(54) Abstract Title
Magnetoresistive layer system

(57) A magnetoresistive layer system comprises reference layer (2), interlayer (3) and detection layer (1). Detection layer (1) has first magnetisation (m_1) and reference layer (2) has second magnetisation (m_2). Reference layer (2) is provided with structuring, in particular an undulatory or sawtooth-shaped topography oriented parallel to the second magnetisation. The second magnetisation direction remains unaltered under the influence of an external magnetic field, whereas the first magnetisation direction alters with the direction of the external magnetic field. The layer system may exist on substrate (10) with buffer layer (11). The detection layer (1) may be a soft magnetic material such as NiFe, and the reference layer (2) may be a hard magnetic material such as Co of uniform magnetic alignment. The structure may also contain stabilising layer (4, Figs. 3 and 4) adjacent reference layer (2) comprising an anti-ferromagnetic material. The system has use as a GMR or TMR sensor, magnetic-disk reading head, or as a magnetic memory element.

FIG. 2

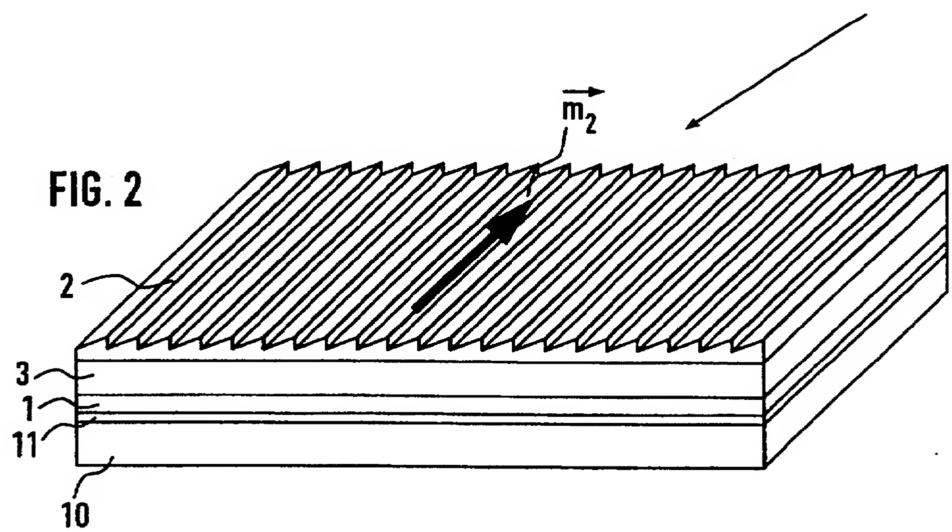

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FIG. 1

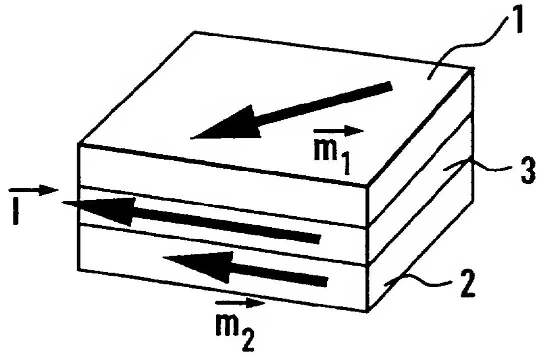


FIG. 2

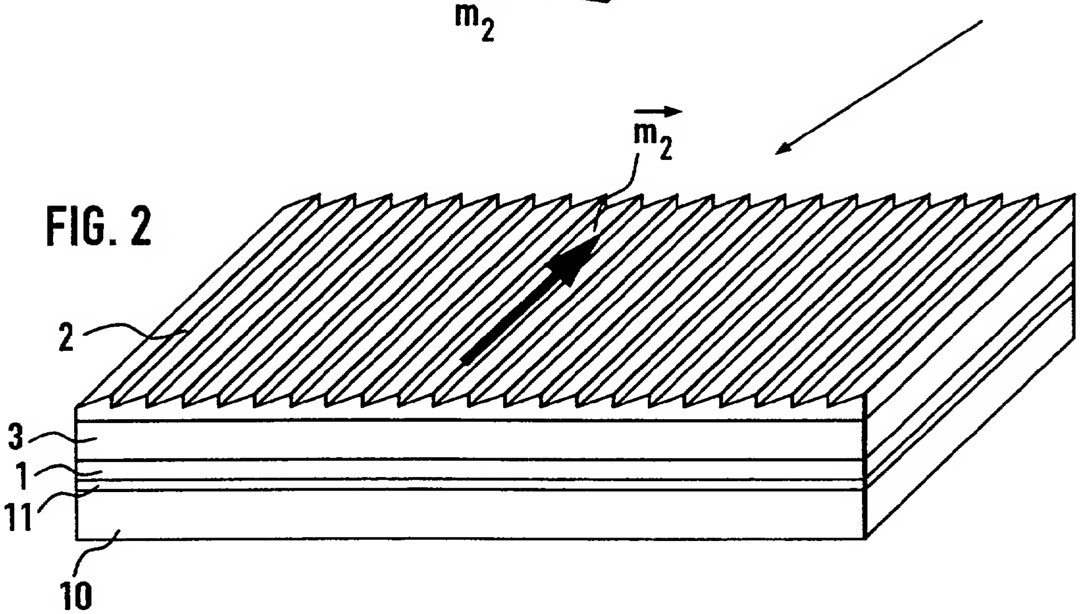


FIG. 3

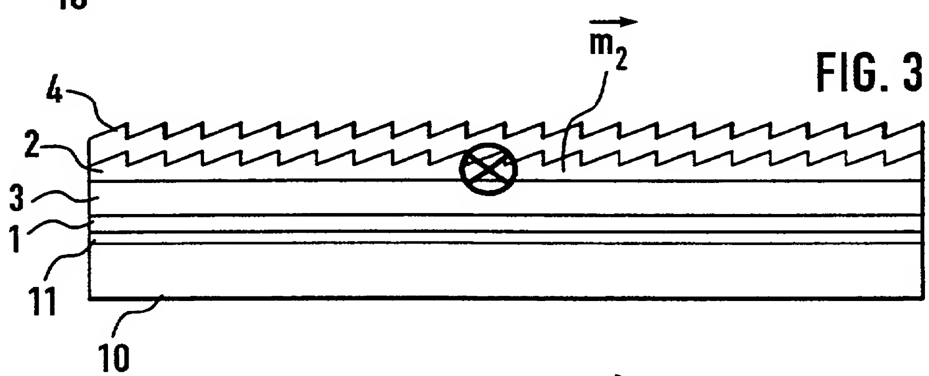
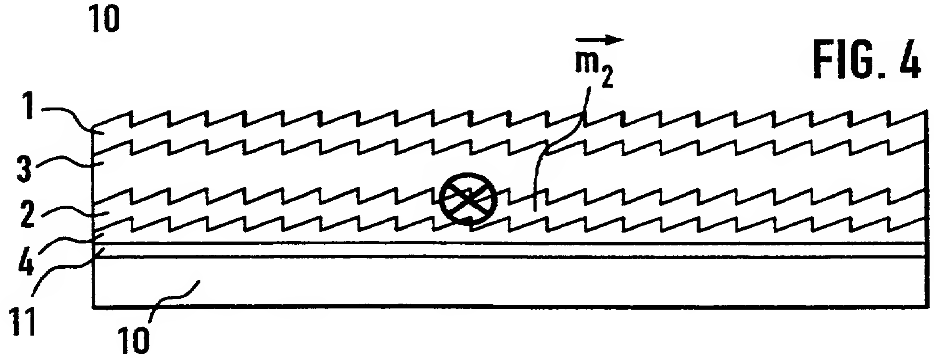


FIG. 4



Magnetoresistive layer system

The invention relates to a magnetoresistive layer system according to the generic class of the main claim.

Prior art

Known magnetoresistive layer systems or sensor elements that function according to the so-called "spin-valve principle" are conventionally composed of a soft-magnetic detection layer having a first magnetization m_1 directed parallel to the detection layer and adjustable by means of an external magnetic field, of a hard-magnetic reference layer having a specified spatial alignment of an associated second magnetization m_2 directed parallel to the reference layer and as invariable as possible, and also of a nonmagnetic metallic interlayer. Given suitable dimensioning of the layer thicknesses and a suitable choice of material, this system then exhibits a change in the electrical resistance in the event of an electrical current flowing within the plane of the interlayer in accordance with

$$R = R_0 + C \cos \theta$$

where θ denotes the angle between the directions of the two magnetizations associated with the reference layer and the detection layer (GMR ["gigantic magnetoresistance"] effect). The change in resistance is typically in the range between 5% and 10% and can be measured by varying the direction of the magnetization m_1, for example by means of an external magnetic field.

The hard-magnetic reference layer is furthermore conventionally composed either of a thin layer of relatively hard-magnetic material or of two layers situated above one another in the form of a soft-magnetic or relatively hard-magnetic layer adjoining the interlayer and an anti-ferromagnetic layer that determines or stabilizes the spatial orientation of the magnetization of the magnetic layer adjoining the interlayer.

The operation of such magnetoresistive sensor elements is based on the fact that the direction of the magnetization m_1 of the detection layer aligns itself as easily as possible and substantially parallel to a component, situated within the plane of the detection layer, of an external magnetic field, whereas the direction of the magnetization m_2 of the reference layer should remain as unaffected as possible by such external fields so that a reliable reference is guaranteed for determining the angle θ.

Known magnetoresistive sensor elements consequently permit the contactless measurement of external magnetic fields applied to the sensor element in regard to their strength and direction or vice versa, for example for use as a magnetic memory or establishing a desired time-stable magnetization of the detection layer by an external magnetic field.

In relation to further details relating to magnetoresistive layers and possible applications, reference may be made, for example, to C. Tsang et al., "Design, Fabrication and Testing of Spin-Valve Read Heads for High Density Recording", IEEE Trans. Magn., 30, (1994), pages 3801 ff.

Advantages of the invention

The magnetoresistive layer system according to the invention has the advantage over the prior art that the

direction and thereby also the strength of the magnetization of the reference layer is stabilized, with the result that said direction and, consequently, also the strength of the magnetization of the reference layer always remains unaffected even in the case of strong external magnetic fields and, consequently, it is available as a reliable and time-constant reference. In this connection, the external magnetic fields may be both magnetic interference fields and magnetic fields to be measured or generated in a given manner.

This advantageously avoids the possibility that, in addition to a desired variation in the direction of the magnetization of the detection layer, an external magnetic field also acts on the reference layer and, as a rule, results therein in irreversible changes in the direction of the magnetization, which substantially alters, for example, the sensor characteristics of the magnetoresistive layer system.

All in all, therefore, the vulnerability and stability of the direction of magnetization in the reference layer and also the measurement accuracy, in particular in regard to the angular accuracy and a drift with time, of the magnetoresistive layer system according to the invention is markedly improved compared with the prior art.

At the same time, the layer system according to the invention is easy and inexpensive to manufacture, in which connection recourse can be made in particular to methods of manufacture that are known in each case and are readily controllable.

Advantageous developments of the invention result from the measures cited in the subclaims.

Thus, it is particularly advantageous if the structuring of the reference layer is an undulatory or sawtooth-shaped topography having a uniaxial preferred direction, the individual undulations of said topography advantageously being aligned as parallel as possible to the direction of magnetization of the reference layer. This form of structuring results in a particularly stable direction of magnetization of the reference layer, which direction is insensitive to interferences.

It is furthermore advantageous if at least one additional stabilizing layer is provided that is adjacent to the reference layer and that additionally opposes a change in the direction of the magnetization of the reference layer at least in the region of that surface of the stabilizing layer adjacent to the reference layer or stabilizes the direction of magnetization of the reference layer. This is advantageously done by creating a thin anti-ferromagnetic layer having no resultant magnetic moment as stabilizing layer.

Said stabilizing layer is thereby, on the one hand, not affected by an external magnetic field applied during the use of the magnetoresistive layer system, but, on the other hand, the stabilizing layer induces, in a manner known per se, the desired magnetization having a given direction in the adjacent reference layer.

In this connection, the direction of the magnetization induced by the anti-ferromagnetic stabilizing layer in the reference layer can advantageously and easily be adjusted by applying an external magnetic field of given direction during the creation of the anti-ferromagnetic stabilization layer, with the result that the stabilizing layer is already aligned in said magnetic field during deposition in accordance with the desired direction of m_2 and, after the deposition, the finished stabilization layer can no longer

be affected by external magnetic fields applied later because of the absence of a resultant magnetic moment.

The combination of the structuring of the reference layer, i.e. an anisotropy of form oriented according to the desired direction of magnetization, with the anti-ferromagnetic stabilizing layer is particularly advantageous in this connection with regard to a particularly high measurement accuracy and insensitivity to interference of the reference layer with respect to magnetic fields.

Furthermore, it may be advantageous for certain applications if the interlayer and the detection layer are created on the already structured reference layer, with the result that the structuring of the reference layer is transmitted to these two layers. This frequently results in an increase in the magnetic-field-dependent resistance change in the magnetoresistive layer system according to the invention since some of the electrical current previously flowing exclusively in the plane of the interlayer now flows perpendicularly to said layer.

Incidentally, the layer system according to the invention can easily also be operated as a TMR ("tunnel magnetoresistance") sensor element or a TMR memory element. For this purpose, the interlayer has only to be designed in the form of a thin dielectric layer and an electrical current applied perpendicularly to the plane of the interlayer. In this case, the interlayer acts as a tunnel barrier, large resistance changes in said tunnel barrier advantageously occurring for currents perpendicular to the plane of the interlayer as a function of an external magnetic field.

All in all, the layer system according to the invention is advantageously suitable for use in a magnetic memory

element (MRAM = "magnetic random access memory"), a magnetic disk reading head, a GMR sensor (GMR = "gigantic magnetoresistance"), a TMR sensor ("tunnel magnetoresistance") or generally in a magnetic sensor for contactless determination of distance, velocity and angular velocity and also of physical measured variables derived therefrom, for example in motor vehicles.

Drawings

Exemplary embodiments of the invention are explained in greater detail by reference to the drawings and in the description below. Figure 1 shows a magnetoresistive layer system known from the prior art, Figure 2 shows a first exemplary embodiment of a magnetoresistive layer system according to the invention, Figure 3 shows a second exemplary embodiment and Figure 4 shows a third exemplary embodiment.

Exemplary embodiments

Figure 1 first of all shows a basic diagram of a magnetoresistive layer system known from the prior art and having a detection layer 1 composed of a soft-magnetic material and having a magnetization m_1 that has, for example, the direction indicated by the arrow. Furthermore, the layer system has an interlayer 3 composed of an electrically conductive, nonmagnetic material through which a current I flows in the plane of the interlayer 3. Finally, applied to the interlayer 3 on the side opposite the detection layer 1 is a reference layer 2 composed of a hard-magnetic material and having a magnetization m_2 whose direction is given, for example, by the arrow.

As an extension of Figure 1, Figure 2 shows, as a first exemplary embodiment of the invention, a substrate 10, for example a wafer composed of thermally oxidized silicon to

which there has first been applied in a manner known per se by means of a sputtering technique a buffer layer 11 that is 1 nm to 10 nm thick and is composed of a layer of tantalum and a layer of NiFe deposited thereon. In this connection, it should, however, be emphasized that the existence of the buffer layer 11 is not obligatory for the invention since, depending on the material of the substrate 10 and the layer of the magnetoresistive layer system further deposited thereon, the buffer layer may also be dispensed with.

Furthermore, there is deposited on the buffer layer 11 a soft-magnetic layer, for example of NiFe, that has a thickness of 0.5 nm to 10 nm and that serves as detection layer 1 of the magnetoresistive layer system. Furthermore situated on the detection layer 1 is then an interlayer 3 of an electrically conductive nonmagnetic material such as copper that has a thickness of 1 nm to 10 nm and through which an electrical current I can be conducted in a manner known per se parallel to the plane of the interlayer 3 via electrical connections and components, which are not shown. Finally, a hard-magnetic reference layer 2 that is composed, for example, of Co or NiFe having as uniform a magnetic alignment as possible is deposited on the interlayer 3.

In this connection, the reference layer 2 was applied in such a manner that, during the deposition of the reference layer 2, an external magnetic field was applied to the magnetoresistive layer system, with the result that, during the deposition of the reference layer 2, a magnetization m_2 of the reference layer 2 is established that is characterized, in its strength, by the absolute amount of m_2 and, in its direction, by the direction of the component, directed parallel to the plane of the reference layer 2, of the external magnetic field. In Figure 2, the direction of said magnetization m_2 is given, for example, by the arrow

marked in. Furthermore, the reference layer 2 was also deposited in such a manner that structuring of the reference layer 2 in the form of an undulatory or sawtooth-topography having uniaxial preferred direction is produced, the individual structures of said topography being aligned laterally as substantially parallel as possible to the direction of magnetization m_2.

In this connection, said structuring is created during the deposition of the reference layer 2 with simultaneous use of an external magnetic field that is as accurately as possible known with regard to its direction by aligning the substrate 10 at a suitable inclination with respect to a sputtering source or a vaporization device, for example, of a CVD or MBE device known per se and consequently sputtering or preferably vaporizing at a known specified angle. In Figure 2, said direction of vaporization is indicated by an arrow.

All in all, a uniaxial preferred direction of the structuring created there is already consequently produced by means of the nature of the creation of the reference layer 2, the preferred direction furthermore being aligned as parallel as possible to the direction of magnetization m_2. Said structuring of the reference layer 2 effects a marked stabilization of the direction of magnetization m_2 after the production of the layer system with respect to external magnetic fields directed substantially randomly. Consequently, the direction of the magnetization m_2 is given not only by the material characteristics of the reference layer 2, but also by its structure.

When the magnetoresistive layer system according to Figure 1 is operated in a magnetoresistive sensor element, a magnetic moment or a magnetization m_2 that is aligned at least substantially parallel to the plane of the detection layer 1 and, in addition, also at least substantially

parallel to the direction of that component of the external magnetic field situated in the plane of the detection layer 1 (analogously to Figure 1) is induced in the detection layer 1, for example, by means of an external magnetic field to be analysed with regard to its direction. Furthermore, the direction of the magnetization m_2 already impressed during the creation of the reference layer 2 is substantially unaffected by said external magnetic field, with the result that the angle θ between the directions of the magnetizations m_1 and m_2 is a measure of the direction of the external magnetic field. This angle can, however, be measured by means of the GMR effect via the electrical resistance of the interlayer 2 when an electric current is applied that flows in the plane of the interlayer 2.

Figure 3 shows, as a second exemplary embodiment of the invention, an extension of the first exemplary embodiment. For this purpose, with an otherwise identical structure, there was deposited on the reference layer 2 an additional stabilizing layer 4 that has a thickness of 1 nm to 100 nm and is composed of an anti-ferromagnetic material, such as, for example, NiO or IrMn. Said stabilizing layer 4 was deposited after the deposition of the reference layer 2, the external magnetic field applied to create the magnetization m_2 during the deposition of the reference layer 2 also remaining applied unaltered during the deposition of the stabilizing layer.

Consequently, during the deposition of the anti-ferromagnetic stabilizing layer 4, a nonrecurrent, i.e. irreversible, alignment of said stabilizing layer 4 takes place in the external magnetic field in accordance with the desired direction of magnetization m_2. Since the stabilizing layer 4 furthermore has no resultant magnetic moment after the conclusion of the creation of the magnetoresistive layer system and, consequently, also exhibits no outward measurable magnetization, it is insensitive to applied

external magnetic fields and can no longer be influenced by the latter in its alignment.

The alignment of the stabilizing layer 4 took place during the deposition in the applied magnetic field results in it additionally stabilizing and partially also inducing in the adjacent reference layer 2 the spatial orientation of the magnetization m_2 in a manner known per se. The action of the stabilizing layer 4 supplements and, consequently, intensifies the action of the structuring of the reference layer 2.

Incidentally, the structuring of the reference layer 2 is transmitted to the stabilizing layer 4 by its deposition on the reference layer 2, which also results in a uniaxial preferred direction parallel to the direction of the magnetization m_2 in the stabilizing layer 4. This results in a further intensification of the desired stabilization of the direction of m_2 with respect to external magnetic fields but this is acquired by an increased manufacturing cost compared with Figure 2.

Incidentally, if the stabilizing layer 4 is used, it is equally possible still not to apply the external magnetic field impressing the direction of magnetization m_2 during the deposition of the reference layer 2, but only to employ it when the stabilizing layer 4 is deposited. However, this procedure tends to be disadvantageous for the strength and homogeneity of the alignment of magnetization m_2 in the reference layer 2.

Figure 4 shows a further exemplary embodiment of the invention, in which, in this case, only the sequence of the layers 1, 2, 3, 4 of the magnetoresistive layer system was initially modified with respect to Figure 3. Thus, it is, for example, unimportant whether the detection layer 1 or

the reference layer 2 is situated between substrate and interlayer 3.

Since, however, the structuring of the reference layer 2 in accordance with Figure 2 or 3 always also has to be maintained in the exemplary embodiment according to Figure 4, the stabilizing layer 4 having an undulatory or sawtooth-shaped topography was first created on the buffer layer 11, followed by the reference layer 2, by inclining the substrate 10 with the buffer layer 11. The interlayer 3 and, finally, the detection layer 1 were then deposited on said two layers 2, 4 with the result that the structuring of the stabilizing layer 4 is transmitted to the reference layer 2, the interlayer 3 and the detection layer 1. The exemplary embodiment according to Figure 4 is otherwise of unaltered construction compared with Figure 3.

The exemplary embodiment according to Figure 4 has the advantage over Figure 3 that an electrical current conducted within the plane of the interlayer 3 now flows partly or sectionwise also perpendicular to the plane of the interlayer 3 because of the structuring of the interlayer 3 with superficially undulatory or sawtooth-shaped topography on both sides, which results in an increase in the change in the electrical resistance of the interlayer 3 as a function of an external magnetic field (GMR effect).

The exemplary embodiments explained according to Figures 2 to 4, can, incidentally, be constructed so that the interlayer 3 is formed from a dielectric layer, for example from Al_2O_3, with a thickness of 0.5 nm to 10 nm. In this case, an electrical current directed perpendicularly to the plane of the interlayer 3 is applied to the detection layer 1 or the reference layer 2, respectively, that are at least weakly electrically conductive because of the particular materials, in each case via suitable contacts, known per

se, instead of the electrical current previously flowing in the plane of the interlayer 3. In this case, large magnetic-field-dependent changes in the electrical resistance between the detection layer 1 and the reference layer 2 can be achieved by means of an external magnetic field. This effect is also known as the TMR effect ("tunnel magnetoresistance") and makes it possible to use such a magnetoresistive layer system, for example, in magnetic memory elements or magnetic-disk reading heads.

List of reference symbols

1 Detection layer
2 Reference layer
3 Interlayer
4 Stabilizing layer

10 Substrate
11 Buffer layer

Claims

1. Magnetoresistive layer system, in particular for use in a GMR or TMR sensor or as a magnetic memory element, having a reference layer (2), an interlayer (3) adjacent to the reference layer (2) and a detection layer (1) adjacent to the interlayer (3), wherein the detection layer (1) has a first magnetization (m_1) having a first magnetization direction at least in the region of its surface adjacent to the interlayer (3) and wherein the reference layer (2) has a second magnetization (m_2) having a second magnetization direction at least in the region of its surface adjacent to the interlayer (3), characterized in that at least the reference layer (2) is at least superficially and at least in some areas provided with a structuring that opposes a change in the second magnetization direction.

2. Magnetoresistive layer system according to Claim 1, characterized in that the structuring is an undulatory or sawtooth-shaped topography, wherein its structures have at least substantially a uniaxial preferred direction and are oriented at least substantially parallel to the second magnetization direction.

3. Magnetoresistive layer system according to Claim 1, characterized in that the detection layer (1) is disposed on a substrate (10) provided, in particular, with a buffer layer (11), and in that the interlayer (3) is disposed on the detection layer (1) and the reference layer (2) is disposed on the interlayer (3).

4. Magnetoresistive layer system according to Claim 1, characterized in that the reference layer (2) is disposed on a substrate (10) provided, in particular, with a buffer layer (11), and in that the interlayer (3) is disposed on the reference layer (2) and the detection layer (1) is disposed on the interlayer (3).

5. Magnetoresistive layer system according to Claim 4, characterized in that the detection layer (1) has, at least on one side, a structuring, in particular an undulatory topography, that corresponds at least substantially to the structuring of the reference layer (2).

6. Magnetoresistive layer system according to Claim 4, characterized in that the interlayer (3) has, at least on one side, a structuring, in particular an undulatory topography, that corresponds at least substantially to the structuring of the reference layer (2).

7. Magnetoresistive layer system according to Claim 1, characterized in that the second magnetization direction is oriented at least substantially parallel to the plane of the reference layer (2) and the first magnetization direction is oriented at least substantially parallel to the plane of the detection layer (1).

8. Magnetoresistive layer system according to Claim 1, characterized in that the second magnetization direction is always at least substantially unaltered when exposed to an external magnetic field, in particular a randomly oriented one.

9. Magnetoresistive layer system according to Claim 1, characterized in that the first magnetization

direction can be varied under the influence of an external magnetic field, wherein the first magnetization direction is established, in particular, in such a way that it is oriented at least substantially parallel to a component of the external magnetic field directed parallel to the plane of the detection layer (1).

10. Magnetoresistive layer system according to Claim 1, characterized in that the interlayer (3) comprises an electrically conductive material, in particular a metal, or in that the interlayer (3) comprises a dielectric material, in particular Al_2O_3.

11. Magnetoresistive layer system according to Claim 1, characterized in that the detection layer (1) comprises, at least in some areas, a soft-magnetic material, in particular NiFe and/or in that the reference layer (2) comprises, at least in some areas, a hard-magnetic material, in particular cobalt of uniform magnetic alignment.

12. Magnetoresistive layer system according to Claim 1, characterized in that the thickness of the detection layer (1) is between 0.5 nm and 10 nm, the thickness of the interlayer (3) is between 1 nm and 10 nm and the thickness of the reference layer (2) is between 0.5 nm and 10 nm.

13. Magnetoresistive layer system according to at least one of the preceding claims, characterized in that the layer system exhibits a change in the electrical resistance of the interlayer (3) under the influence of an external magnetic field, wherein the change in the electrical resistance is a function of the angle between the first magnetization direction (m_1) and the second magnetization direction (m_2).

14. Magnetoresistive layer system according to Claim 13, characterized in that the electrical resistance of the interlayer (3) is that electrical resistance that can be measured in the case of an electrical current conducted parallel or perpendicularly to the plane of the interlayer (3).

15. Magnetoresistive layer system according to at least one of the preceding claims, characterized in that at least one stabilizing layer (4) is provided that is adjacent to the reference layer (2) and that opposes, at least in some areas, in particular in the region of that surface of the stabilizing layer (4) adjacent to the reference layer (2), a change in the second magnetization direction (m_2) of the reference layer (2) under the influence of an external magnetic field.

16. Magnetoresistive layer system according to Claim 15, characterized in that the stabilizing layer (4) has no resultant magnetic moment and induces in the reference layer (2), at least superficially, a magnetization whose magnetization direction is at least approximately parallel to the second magnetization direction (m_2).

17. Magnetoresistive layer system according to Claim 15 or 16, characterized in that the stabilizing layer (4) comprises an anti-ferromagnetic material, in particular nickel oxide or IrMn, in particular in the region of the surface adjacent to the reference layer (2), and has a thickness of 1 nm to 100 nm.

18. Magneto resistive layer system substantially as hereinbefore described with reference to Figure 2 of the accompanying drawings.

19. Magneto resistive layer system substantially as hereinbefore described with reference to Figure 3 of the accompanying drawings.

20. Magneto resistive layer system substantially as hereinbefore described with reference to Figure 4 of the accompanying drawings.

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Application No:	GB 0025193.4	**Examiner:**	T P Marlow
Claims searched:	1 to 20	**Date of search:**	25 July 2001

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UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H1K: (KFB) H3B: (BDC) (BDF)

Int Cl (Ed.7): G01R G11B G11C H01F H01L

Other: ONLINE: WPI, EPODOC, JAPIO, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	US 5942309	NEC - see especially reference layer (3), detection layer (5), and interlayer (4) in Fig. 1, and col.14 line 65 to col.17 line 16	1 to 16

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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